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14. ABSTRACT We report here single layer ultra-compact Fano resonance photonic crystal membrane reflectors at mid-infrared and far-infrared bands, based on single layer crystalline Si membranes. High performance reflectors were designed for surface-normal incidence illumination with center operation wavelengths of 1.5 um, 8 um, and 75 um, respectively. Large area patterned membrane reflectors were also fabricated and transferred onto glass substrates based on PDMS stamp assisted membrane transfer processes. Close to 100% reflection was obtained at ~76 um, with a single					
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Report Title

Fano Resonance Membrane Reflectors from Mid-Infrared to Far-Infrared

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We report here single layer ultra-compact Fano resonance photonic crystal membrane reflectors at mid-infrared and far-infrared bands, based on single layer crystalline Si membranes. High performance reflectors were designed for surface-normal incidence illumination with center operation wavelengths of 1.5 μm , 8 μm , and 75 μm , respectively. Large area patterned membrane reflectors were also fabricated and transferred onto glass substrates based on PDMS stamp assisted membrane transfer processes. Close to 100% reflection was obtained at $\sim 76 \mu\text{m}$, with a single layer Si membrane thickness of 18 μm . Such Fano resonance based membrane reflectors, offer great opportunities for high performance ultra-compact dielectric reflectors at infrared and THz regions.

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Fano Resonance Membrane Reflectors from Mid-Infrared to Far-Infrared

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Compact broadband reflectors (BBRs) are of great importance for optoelectronic devices and photonic integrated circuits like lasers, photodetectors, solar cells, and sensors, etc. Traditionally, they can be realized by using metal films or stacked dielectric thin films. Metal films can offer larger reflection bandwidth but are limited by their intrinsic absorption losses. Stacked dielectric thin films can achieve very low losses. But they typically require many individual layers with stringent refractive index and thickness tolerances for each layer. It becomes more of an engineering challenge to realize extremely high reflection DBRs at longer wavelengths, including mid-IR, far-IR, and THz frequencies, due to the scaling of quarter-wavelength stack dielectrics.

Recently, BBRs based on Fano resonance, or guided mode resonance [1, 2], have attracted great attention, where high reflections can be obtained with a single layer one-dimensional (1D) grating, or a two-dimensional photonic crystal slab (2D PCS) structure. By properly controlling the design parameters, very broadband reflectors can be obtained. Based on crystalline membrane transfer, high performance membrane reflectors (MRs) at near-IR (1550nm) have been reported recently based on crystalline Si on SOI and on glass substrates. [3, 4]

We report here single layer ultra-compact Si MRs at mid-infrared and far-infrared bands, based on suspended air-clad structure. High performance reflectors were designed for surface-normal incidence with center operation wavelengths of 1.5 μm , $\sim 8 \mu\text{m}$, and 75 μm , respectively. Large area patterned membrane reflectors were also fabricated and transferred onto glass substrates based on PDMS stamp assisted membrane transfer process. Close to 100% reflection was obtained at $\sim 76 \mu\text{m}$, with a single layer Si membrane thickness of 18 μm .

The design was done based on finite difference time-domain (FDTD) simulation and rigorous coupled-wave analysis (RCWA) techniques. A sketch of Si MR on glass is shown in Fig. 1(a). Shown in Figs. 1(b-d) are the simulated reflector performances for designs at three different wavelength bands. All designs are based on suspended (in air) Si MR configurations. Broadband reflection with 100% peak reflection is possible for all designed wavelength bands, with the optimal selection of lattice parameters and Si thicknesses.

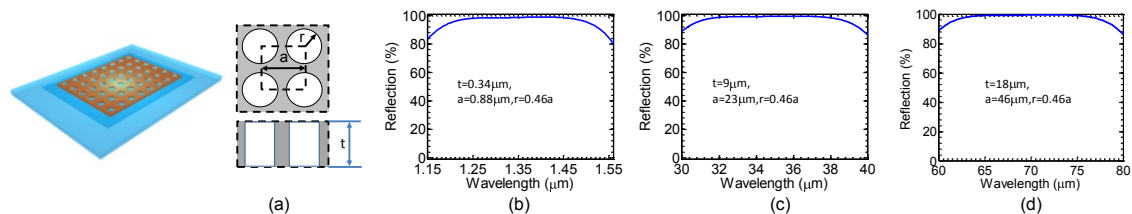


Fig. 1 (a) 3D sketch of a Si membrane reflector with a patterned 2D air hole square lattice photonic crystal structure on glass substrate; (b-d) Simulated reflector performances for designs at three different wavelength bands. Key design parameters shown are Si thickness (t), lattice constant (a), and air hole radius (r).

Large-area Si MRs were fabricated based on photolithography and deep reactive-ion etching (DRIE) process on SOI substrates. The patterned Si membrane structures were later released by selective buffered HF (BHF) etching of buried oxide (BOX) layer underneath, and transferred onto foreign substrates, based on wet transfer technique.[5] Shown in Fig.2 is the

device structure and measured reflection spectra for a MR structure with design center-wavelength of 8 μm . Both top and cross-sectional scanning electron micrograph (SEM) images are shown in Fig. 2(a), along with a 1 x 1 cm^2 MR reflector micrograph shown in the inset. Shown in Fig. 2(b) is a reflection spectrum measured at 23.6° off-surface-normal using a 15x, 0.4NA reflecting lens associated with a micro-Fourier Transform Infrared (FTIR) spectrometer. Notice that the peak reflection band at $\sim 8 \mu\text{m}$ overlaps the strong absorption band associated with the buried oxide layer of the SOI used for the reflector, therefore the peak reflection of the MR at this wavelength band will be limited by the oxide absorption. Improved reflection would thus be possible by removing the buried oxide underneath the Si MR.

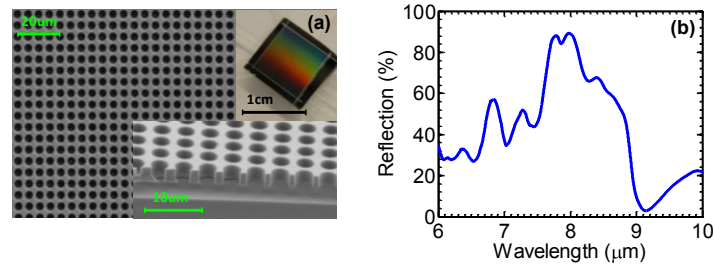


Fig. 2 (a) A scanning-electron micrograph (SEM) of the MR top view, along with insets showing a SEM cross-sectional view and a micrograph of the complete MR structure; (b) Measured reflection spectrum for a mid-IR MR reflector with reflection band centered at 8 μm .

Similarly, far-IR MR reflector was designed and fabricated on SOI substrates, with a Si membrane thickness of 18 μm and a center wavelength of 75 μm . The patterned Si membrane structures were later released and transferred onto glass substrates. In order to minimize the impact of the buried oxide, a suspended Si MR reflector structure was designed and fabricated whereby the center region of the glass substrate was etched away. A SEM micrograph of this structure is shown in Fig. 3(a), for a far-IR MR reflector transferred to glass, with a center opening producing a suspended Si MR reflector. Also shown in Fig. 3(a) are top and cross-sectional SEM images. Shown in Fig. 3(b) are measured and simulated surface-normal reflection spectra derived from FTIR transmission measurements. Assuming no absorption in the spectral band, we can obtain close to 100% reflection at roughly 76 μm wavelength. The absolute reflection of these optical elements is ongoing and is being obtained by measuring the finesse of a Fabry-Perot cavity formed by a pair of these Si MR reflectors.

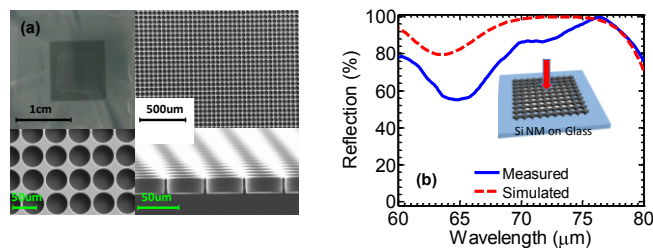


Fig. 3 (a) A micrograph of a fabricated far-IR MR reflector, transferred onto a glass substrate. Also shown are SEM top and cross-sectional views. (b) Measured and simulated reflection spectra for a suspended Si MR on glass.

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References:

- [1] R. Magnusson and S. S. Wang, "New principle for optical filters," *Appl. Phys. Lett.*, vol. 61, pp. 1022-1024, 1992.
- [2] S. Fan and J. D. Joannopoulos, "Analysis of guided resonances in photonic crystal slabs," *Phys. Rev. B*, vol. 65, p. 235112, 2002.
- [3] W. Zhou, Z. Ma, H. Yang, Z. Qiang, G. Qin, H. Pang, L. Chen, W. Yang, S. Chuwongin, and D. Zhao, "Flexible photonic-crystal Fano filters based on transferred semiconductor nanomembranes," *Journal of Physics D: Applied Physics*, vol. 42, pp. 234007-234017, 2009.
- [4] Z. Qiang, H. Yang, S. Chuwongin, D. Zhao, Z. Ma, and W. Zhou, "Design of Fano Broadband Reflectors on SOI," *Photonics Technology Letters, IEEE*, vol. 22, pp. 1108-1110, 2010.
- [5] H. C. Yuan and Z. Ma, "Microwave thin-film transistors using Si nanomembranes on flexible polymer substrate," *Applied Physics Letters*, vol. 89, p. 212105, 2006.